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OVERVIEW

FLUID ACQUISITION AND TRANSFER

Jere S. Meserole
Boeing Aerospace Company
Seattle, Washington

This brief overview introduced the symposium session on microgravity fluid acquisition and transfer. It states the objective of NASA efforts in this technology and the approach being taken in the technology program. The problems are outlined and various methods for low-gravity fluid acquisition and transfer are summarized. Applications for the technology are described and an assessment of the current state of the art is presented. NASA and DoD on-going and planned programs are listed.

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INTRODUCTION

The overall objective of NASA efforts in microgravity fluid management is to develop the technology required for efficient fluid systems in space. The technology is applicable to both cryogenic and space-storable liquids, but current research emphasizes technology for managing cryogenic propellants, since there is little proven technology for in-space handling of cryogenics. The research efforts include analysis, computer code development, and experiments. Verification of the analytical models and the codes is an important element of the program.

This session of the symposium emphasizes issues pertaining to liquid acquisition and transfer in microgravity, although many of the papers present research results that are equally important to in-space fluid storage. The term "acquisition" encompasses all methods for positioning the liquid contents of a storage tank at the tank outlet and ensuring vapor-free extraction of the liquid. "Transfer" includes all aspects of filling one tank (e.g., a vehicle propellant tank or a storage tank) from another while in orbit.

Low-Gravity Fluid Acquisition and Transfer Technology

Overall Objective: Provide technology to enable design of efficient systems for managing fluids in the space environment

General Approach: Perform experiments to verify analytical models and scaling techniques

Acquisition = Positioning liquid at the tank outlet for withdrawal

Transfer = On-orbit tank fill or refill. Includes:

- Supply tank pressurization
- Receiver tank pressure control
- Chilledown
- Venting

Figure 1

APPLICATIONS

Applications for microgravity fluid management technology will include (1) propellant management in launch vehicle upper stages and orbiters; (2) on-orbit fueling of satellites and propulsion stages (including the Orbital Maneuvering Vehicle and the Orbital Transfer Vehicle), so they can be designed for launch without the loads associated with on-board propellant and/or for space-based reuse; (3) replenishing fluid subsystems on the Space Station; (4) resupplying propellant and other liquid consumables on space experiments and satellites to extend their service lives; and (5) supplying the liquids required for operation of space-based lasers, particle beam weapons, and other military platforms.

Potential Applications

- Earth-to-orbit transport vehicles
- On-orbit fueling of satellites and propulsion stages
- Space Station subsystems replenishment
- Experiment and satellite fluid resupply
- Resupply of reactants, fuels, coolants, and propellants for space-based directed-energy weapons

Figure 2

FLUID ACQUISITION AND TRANSFER METHODS

Many methods exist for liquid acquisition in low gravity and several have been demonstrated in practice. Some are used routinely in operational vehicles and satellites. The needs for further research and development rest principally in the areas of cryogenic fluid management and systems reusability. Four general approaches to liquid acquisition that are suitable for cryogenics are (1) propulsive settling, (2) start baskets, (3) screened channels, and (4) vanes. The first two are applicable to vehicles and the last two to microgravity fluid transfer. The design of acquisition devices is particularly difficult for liquid hydrogen, because of its low surface tension and relative ease of vaporization.

Screened channels forming what is called a total-communication liquid acquisition device will likely be the approach used in on-orbit cryogen storage tanks. Vane systems cannot reliably position low-surface-tension fluids in the presence of disturbances. No significant low-gravity acquisition and transfer data has yet been obtained for liquid hydrogen and oxygen.

Liquid Acquisition

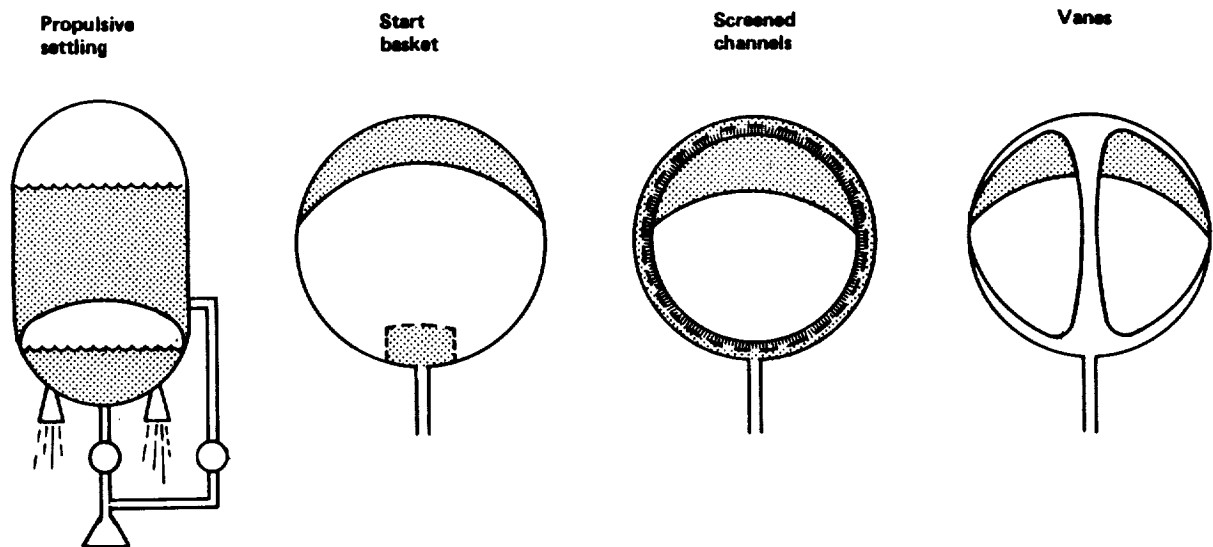


Figure 3

Methods for fluid transfer in microgravity can be classified as one of two general approaches: fluid dynamic or thermodynamic. The difference between them is in how the problem of venting the receiver tank ullage is handled. With the fluid dynamic approach, small acceleration forces (e.g., from vehicle drag, tethering, or small thrusters) or surface-tension liquid positioning devices are used to orient the liquid contents of the tank away from the vent. The liquid inflow rate must be small to avoid breaking up the liquid-vapor interface.

With thermodynamic approach, the ullage is compressed and condensed using the cool incoming liquid as a heat sink for the heat of condensation. This is the favored approach for cryogenics. It avoids the need for venting during all but the chilldown phase of the transfer process. With a tank that is initially empty and warm, first a small amount of liquid is admitted to the tank, allowed to vaporize and chill the tank, and then vented.

Fluid Transfer

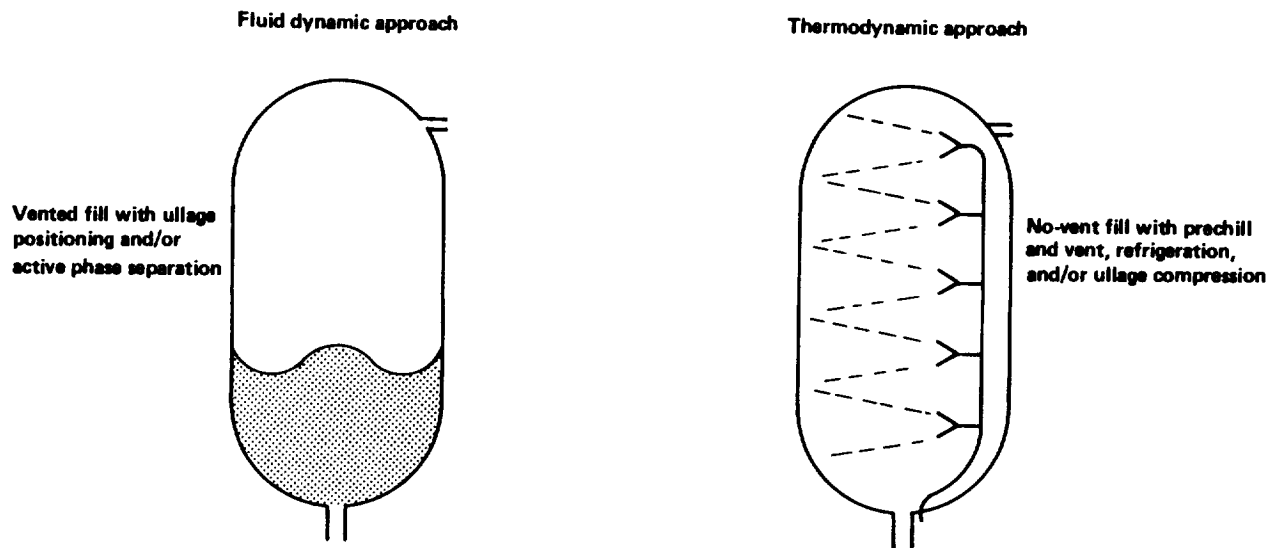


Figure 4

STATE OF THE ART

The state of the art in liquid acquisition comprises space-proven, operational components for noncryogenic liquids but only unproven concepts for cryogens. Some normal-gravity laboratory tests have been conducted with small-scale cryogen systems. Microgravity flight experience with cryogen surface-tension liquid acquisition devices, slosh control, autogenous tank pressurization systems, and mass gaging is virtually nonexistent. Numerical modeling capability for microgravity fluid motion and thermodynamics is under development. One code developed for the NASA Lewis Research Center (called NASA-VOF2D) has just become available.

State-of-the-Art Assessment – Liquid Acquisition

- Surface-tension liquid acquisition devices
 - Flight experience with noncryogenic liquids (no performance data)
 - Small cryogenic system tests and screen characterization studies conducted in laboratory environment
- Fluid dynamic behavior
 - Some limited flight experience
 - Analytical correlations based on drop tower experiments
 - Numerical modeling capability under development
- Pressurization systems
 - Orbital data has been used to establish correlating parameters for high liquid outflow rate helium pressurant systems
 - Limited experience with autogenous pressurant systems
- Mass gaging instrumentation
 - Flight experience with noncryogenic liquid
 - Seek and develop activity underway at JSC

Figure 5

On-orbit transfer of a noncryogenic liquid (hydrazine) has been demonstrated on the Shuttle, and an operational system is under development at the Johnson Space Center (JSC) as part of the Orbital Spacecraft Consumables Resupply Systems program. Considerable activity is underway at NASA in conjunction with the Space Station program and within the military (e.g., the spacecraft Assembly, Maintenance, and Servicing study) to identify systems requirements for fluid resupply operations and to develop the necessary automation and robotics.

For cryogenics, the data available is nearly all from ground-based testing. Some small-scale low-gravity data for liquid nitrogen was obtained in the NASA LeRC 5-second drop tower. On orbit test data for tank chill, no-vent fill, autogenous pressurization, fluid metering, line connect and disconnect, and leak detection are necessary.

State-of-the-Art Assessment – Fluid Transfer

- Transfer line and receiver tank chilldown
 - Analytical models and experimental data available for cryogen systems in normal gravity
 - Limited data obtained with LN₂ in NASA drop tower
- No-vent fill
 - Limited IR&D laboratory testing performed
- Fluid mass and quality metering
 - Limited cryogenic IR&D laboratory testing performed
- Quick disconnect
 - Development activity for space application, including instrumentation for leak detection, recommended by SSTSC

Figure 6

NASA AND DOD PROGRAMS

Several NASA and Department of Defense research programs and studies are addressing issues pertaining to microgravity fluid management. Few of them involve hardware at present, but many are concept and design studies intended to evolve into hardware development.

The NASA Cryogenic Fluid Management Flight Experiment program, for example, is currently designing a sophisticated space experiment for demonstrating technology and methods for storing and transferring liquid hydrogen. Studies of space tethers and of shuttle external tank propellant scavenging may lead to space experiments relatively soon. The Space Infrared Telescope Facility will require helium and propellant resupply. Two-phase thermal transport loops for the Space Station require technology for fluid handling. The Air Force Rocket Propulsion Laboratory is beginning a hardware development program for toroidal tanks for cryogenic upper stages and is planning a fluid management space experiment.

Current and Planned Programs - NASA and DOD

- Cryogenic Fluid Management Flight Experiment
- Orbital Transfer Vehicle
- Orbital Maneuvering Vehicle
- Shuttle propellant scavenging
- Space tethers
- Space Infrared Telescope Facility
- Mass gaging
- Space Station thermal control technology
- Storable Fluid Management Demonstration
- Orbital Spacecraft Consumables Resupply Systems
- Long-Term Cryogen Test Bed
- Helium Transfer Experiment
- Compact LOX Feedsystem (RPL)
- Fluid Management Flight Experiment (RPL)

Figure 7

SUMMARY

The needs for acquiring data on fluid behavior in microgravity and to demonstrate concepts and technology are well characterized. Some ground testing is on-going at NASA, in the military, and in industry, but normal-gravity experiments cannot in many circumstances adequately simulate important microgravity phenomena.

The papers in this section describe several current studies intended to lead eventually to space experiments. Among the topics covered are numerical modeling, fluid slosh and fluid-vehicle dynamic interaction, mass gaging, jet mixing and ullage condensation, the Cryogenic Fluid Management Flight Experiment, and methods for managing superfluid helium in microgravity.

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